Energy Efficient Architectural Design Strategies in Hot-Dry Area of Iran: Kashan

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ABSTRACT

Climate had a major effect on the performance of the traditional building architecture and its energy consumption in hot dry area of Iran. Lack of water and energy sources in these areas forced people to build their houses with some strategies based on minimum energy consumption. Heating and cooling usually use largest portion of energy in buildings. Therefore, builders tried to use natural climatic strategies for coping with harsh conditions. These strategies include: layout orientation, distance between buildings, building orientation & form, climatic elements such as Eyvan (porches), wind catchers, central courtyard, and so on.

The paper first aims to introduce these strategies and then, to categorize these characteristics at three levels:

a) macro scale,

b) medium scale and,

c) micro scale.

In addition, the mentioned strategies will be explained in their level of performance and the relevant elements in other levels. Furthermore, the paper aims to put forward basic principles and changes in their usage that may be of benefit in sustainable housing designs in the future. In this study, the cited design strategies will be examined and modern and traditional houses will be evaluated in terms of design criteria - such as, selection of the area, distance between buildings, orientation, building envelope and building form. In this paper, a simplified evaluation and comparison of a traditional house with a contemporary house will be given.

Keywords: *climate responsive design, design strategies in hot dry area, traditional architecture, sustainable design, Iran, Kashan.*

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1. INTRODUCTION

Climate has a major effect on the performance of the building and its energy consumption. Reducing energy consumption, using natural resources and providing comfortable, healthier and sustainable living spaces are the aims of a climatically responsive sustainable building design (Hui 2000). Sustainable design and construction strategies are of great importance nowadays. One may say that sustainability was already a driving force in the past, exhibiting its validity through the different forms and techniques used. Therefore, from Vitruvius till today, problems and precautions in design and construction did not change fundamentally, although many developments have been seen in materials and technology. Moreover, these developments may have had some negative effects. That is the reason why the building process should be discussed in a holistic way. In other words, climatically responsive design, selection of materials and building techniques must be evaluated together and the final product should perform well during its whole service life. Sustainability, which is presented as a 21st century concept, has been in fact applied since Vitruvius wrote his books and was realized spontaneously in traditional architecture (Vitruvius 1969). When sustainable design and construction strategies of Iran's traditional architecture are under scrutiny, then it is possible to observe how traditional buildings and settlements in this region were designed in harmony with the local cultural, topographical and climatic conditions and how their design and construction could be integrate in today's design practices.

This study is based on a research program, which has been carried out on building techniques used in the hot-dry areas of Iran. The study first aims to show the similarities and the differences of the traditional housing principles in climate responsive design point of view. Secondly, it aims to put forward the basic principles and their meaningful changes in usage that can be used for sustainable housing designs of the future. In this study, design strategies in hot and dry climate were examined and modern and traditional houses were evaluated in terms of design criteria, such as selection of the area of the dwelling, distance between buildings, orientation, building envelope and building form.

2. CLIMATE RESPONSIVE DESIGN STRATEGIES IN HOT AND DRY AREA

The most important design parameters affecting indoor thermal comfort and energy conservation in building scale are distances between buildings, building form, building envelope design, self-efficiency in building materials and optical and thermo-physical properties of the building envelope. Among these parameters, building envelope design, as it separates the outdoor and indoor environment, is the most important. All of these parameters are related to each other and the optimum values of each should be determined depending on the values of the others and their optimum combination should be determined according to the climatic characteristics of the region.

Kashan: Kashan is a city in the central region of Iran and is located in the province of Isfahan. The climate of central region of Iran is relatively similar to desert climate. This region represents a hot and dry area with a high temperature difference between day and night. Through evaluating traditional architectural examples, it can be seen that designers recognized the difficulties and presented the most suitable designs and examples of settlements for each climatic region based on this three scales; macro, medium, and micro scale.

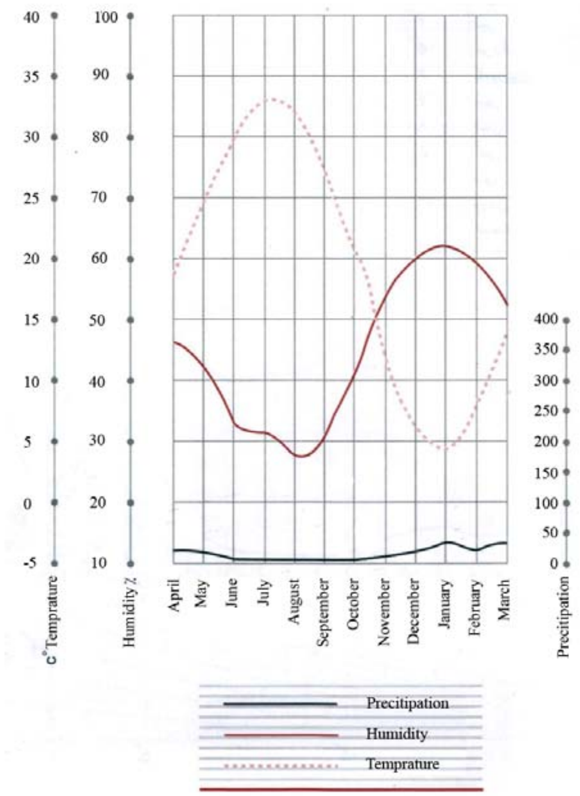

Table 1: Climatic information of Kashan

3. CLIMATE RESPONSIVE DESIGN STRATEGIES IN KASHAN

3.1 Macro climate responsive design strategies

Distance between buildings: In the design of traditional houses in the hot and dry area in Iran, there are several precautions taken to mitigate the temperature extremes. Houses are surrounded by high walls and isolated from the street. During the day, external walls of houses usually provide shady areas in narrow streets and especially in courtyards. By means of thick and heavy walls, a cooler environment in summer and a warmer environment in winter can be provided easily.

Enclosed urban environment: As a whole, the city structure resembles a battlement fully enclosed from all directions which prevents the invasion of enemies from any side. In fact, it is for both defense purposes and to prevent high velocity winds and sand storms from penetrating into the town. For that reason, the appearance of the inside of the city is completely different from the outside, and the air inside is more static than outside the city.

Narrow and irregular streets: The main streets in the town face the direction of the prevailing wind. Of course, the streets are narrower than streets built for other purposes (in other regions). Surely if the streets were not narrow more sand would have been blown into the streets from the desert and ferocious winds would have penetrated into the city districts. Meanwhile the compact nature of the buildings prevents very high temperatures to develop by exposure to the sun.

Figure 1: Narrow and irregular street in compact texture of Kashan.

3.2 Medium climate responsive design strategies

Building form: In Iran, in a hot and dry climate, the most preferred house plan is one with a courtyard. In order to minimize the area affected by the solar radiation, compact forms are chosen. By arranging those forms with courtyards, shady areas can be obtained. In courtyards, with the help of water and plants for evaporative cooling, the floor temperature can be minimized by the high walls surrounding the courtyard, shady areas can be obtained and the open areas can be used during the day. Channels for water poured out from the pool are important elements for cooling. Water is often spread by channels to the floors of the courtyard and evaporative cooling from the surface of the courtyard floors which are made of porous stone contributes to that effect. Courtyards are always on the ground floor and have different forms depending on the landscape of the house.

Building envelope: Sustainability and energy efficiency are greatly affected by a building's skin. The amount of surface area, material choice and insulation strategies are key elements in buildings located in Kashan. The buildings are built in cubic forms and architects tried to minimize the ratio of outdoor surfaces of buildings to the space required instead for habitation. Cubic forms helped buildings to have a lower exposure to hot weather factors than more linear forms of building.

Self-Efficiency in materials: The use of local materials to reduce energy expenditure during the occupation is a wise decision since it will also reduce the initial embodied energy as well as cost, especially transportation cost (Utama and Gheewala 2009). Every building material in a desert town is composed of mud and its derivatives. In fact, nothing but mud and mortar can be used in such regions because there are no other building materials in the region. Here one must refer to the question of self-sufficiency in desert regions because all the earth excavated during housing construction is used as building material in the form of mud. In such regions, one cannot find any other building material except unbaked bricks and mud which strongly resist the incessant sun rays in the very warm months of July and August. In the meantime during cold seasons the chambers are warmed with very little additional heat and even the unbaked brick walls turn into massive and intact blocks after drying and are fully resistant and hardy.

Due to very hot temperatures, the building materials absorb heat from the sun and make it available later when the sun goes down. In other words, this energy is retained in the walls about 8 hours and the other parts of the building envelope and is gradually transferred to the inner compartments. Such a quality provides leads to two alternatives in cold and warm seasons.

In cold seasons the absorbed temperature serves as an isolation barrier which protects the inside air from being affected by the chilly winter desert climate specially at nights because during daytime the temperature is absorbed by the walls and the building and although the air is cold outside, the inside of the house remains warm. During hot seasons the absorbed temperature causes problems and the conditions inside the building prevents full comfort for residents. As a result during nights the people prefer to sleep on the roofs for comfort.

Use of vernacular materials such as brick and adobe is always one of the concerns in the architecture of Kashan buildings. As an illustration, they used to use excavated foundation soil in order to make bricks. There are many examples like this which are incorporated in today's architectural concepts for sustainable building design .Vernacular material selection, compatibility, embodied energy, application of passive energy and design environmental strategies in waste and technology management concerning the impacts in the environment are all concepts that are part of sustainable building design (Vakili and Boussabaine 2006). There are many examples of mosques, public baths, schools and different kinds of buildings in Kashan which have been made of vernacular materials. Many of these buildings are preserved by archeologists and conservators.

Optical and thermo-physical properties of the building envelope: In the hot and dry climatic areas in Iran, in examples of traditional architecture, to benefit from the time lag of temperatures in the building envelope, materials with greater thermal mass have been chosen. These kinds of thermally massed envelope details are very convenient for continental climates, where the summers are very severe with high swings in daily temperature variations. This big thermal mass will slow down the heat transfer through the envelope and thus higher day-time temperatures will be reached indoors although outdoor air temperature is much lower and consequently more stable indoor thermal conditions will be provided. On the other hand this thermal mass, which has higher surface temperature on outer side will rapidly lose heating energy to the atmosphere via radiation at night to start the next day from a cooler level (Yılmaz 2004).

When observing traditional examples, it can be seen that the transparency ratio of the building envelope is chosen as low as possible and the opaque parts of building envelope were constructed by the materials with a high heat capacity as thick as possible. The high heat capacity of the opaque component provides a high time lag for the transmission of the outside temperature to the internal area while the low transparency ratio minimizes the direct solar radiation gained through the windows (Holman 1976).

By means of the high heat capacity of the building envelope, the effect of the outside temperature is minimized and a cooler internal area can be obtained during the day. Therefore, calcareous rock, stone, mud and the combinations of those materials are always preferred in this climate (Yılmaz, 2004). Calcareous rock, which is a sort of porous limestone, is an especially better insulator against cold and warm air and regulates the humidity of the living place. In this climate other precautions against the solar radiation are;

- minimization of the area and the number of windows;

- construction of windows at a high level to block floor radiation;

- minimization of the absorption of heat by facades by choosing white or light paint colors;

- providing natural ventilation especially at night;

- constructing a part of the house below grade, which is always cooler than the ambient outside temperature in summer (Rapoport 1969).

3.3 Micro climate responsive design strategies

Module Construction: The basic unit of measurement in traditional buildings of Iran is called Peymoon. This unit (module) is a base for other measurements in construction. This means that other parts of building are laid out based on this module and the dimensions are a proportion of this unit. All elements of traditional buildings used to be built based on this unit and specific proportions in the building system. This system of measurement allowed stakeholders to use specific geometries of buildings and obtain the advantages of structural resistance found to be suitable (Vakili & Boussabaine 2006).

Eyvan and Revak: Eyvan and Revak, semi-open areas, are used to create shady and cool living spaces during the day. The Eyvan, three side a closed passageway in front of the ‘‘rooms’’, permits a common life inside (an open living room inside the house). Usually they are oriented to the south. Especially, south and east oriented Eyvans are very cool and provide shady places during summer afternoons. The Revak semi-open colonnade arranged in the courtyard always provides shady areas.

Wind catcher (Air trap): Traditional architects were obliged to rely on natural ventilation to render the inside condition of the buildings more pleasant. Use of arched towers became popular 3000 years before the birth of Christ and is the best example of successful implementation of natural forces.

The air trap was a common specific feature of architecture found in the majority of warm regions. Air traps were normally positioned in a suitable location in the house according to the size of the building, and the number of air traps that were necessary to cool the summer apartment. In cities where suitable wind blows from a specific direction, the air trap is open to one direction and closed to the other three directions.

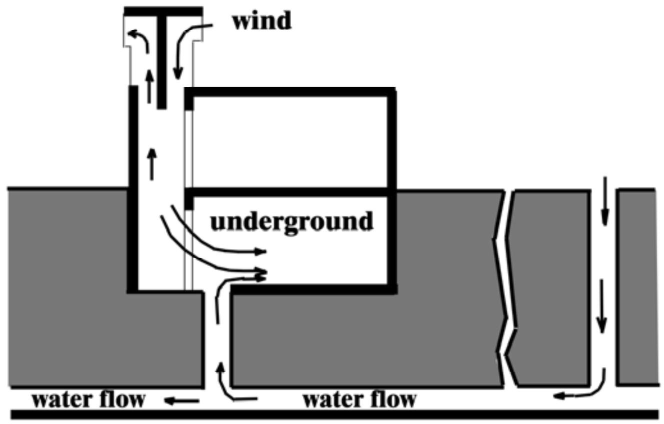

Figure 2: The function of a wind catcher.

In ancient times and in traditional buildings in arid and dry regions the air trap functioned like the present modern air conditioning system. Air trap is like a chimney whose end is underground and the top is elevated above a specific height on the roof. At the upper outlet many small openers or ducts may be set. At the end of the air trap at the bottom of the door, often a pool is set whose water was provided by qanats (aqueducts). The height of air trap, the number of openers and the location of the air traps depends on the location of building in city.

The air trap operates with the change of air temperature and the difference in density of the air inside and outside the trap. The difference of density of the air impels a positive or negative buoyancy which causes the air to flow either to the bottom or to the top. Air circulation in various locations in the building is adjusted by opening or closing the various openers or ducts at the bottom of the air trap.

The air trap operates in response to the condition of the wind and sun radiation in the region. The inside and outside walls absorb a lot of temperature during daytime. As a result they cause a balance of temperature at night and bestow the attracted warmth to the cold night air. The thickness of the air trap walls and the dimension of the holes inside it are designed in a manner to allow enough heat to be transferred for better comfort. The light warm air inside the air trap ascends and is sucked away at the upper elevation. As a result cool air flows from windows and doors into the house and continues all night.

The air trap operates according to the condition of the wind and sun radiation in the region. The inside and outside walls absorb a lot of temperature during daytime. As a result they cause a balance of temperature at night and bestow the attracted warmth to the cold night air. The wind catcher functions on several principles. They are built with their long ventilation shafts positioned to catch any hint of a passing breeze to channel down into the house. The interlinking rooms of old buildings were designed to circulate the air that fluted down the wind catchers.

The sun-dried mud bricks that were used to build the houses retained their coolness in the summer and their warmth in the bitter winters. The air was channelled all the way down to the elaborate function rooms built in the basement where the family would mostly live in the stiflingly hot summers.

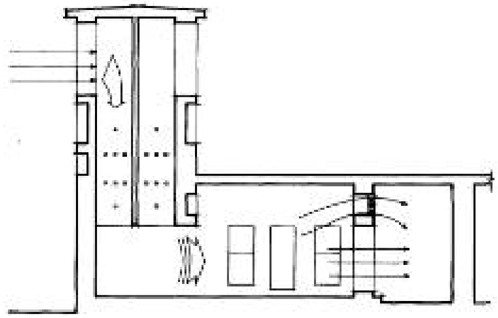

Figure 3: Cross Section of a wind catcher.

Finally, in a windless environment or waterless house, a wind catcher functions as a stack effect aggregator of hot air. It creates a pressure gradient which allows less dense hot air to travel upwards and escape out the top. This is also compounded significantly by the day-night cycle mentioned above, trapping cool air below. The temperature in such an environment can't drop below the nightly low temperature. These last two functions have gained some ground in Western architecture, and there are several commercial products using the name wind catcher.

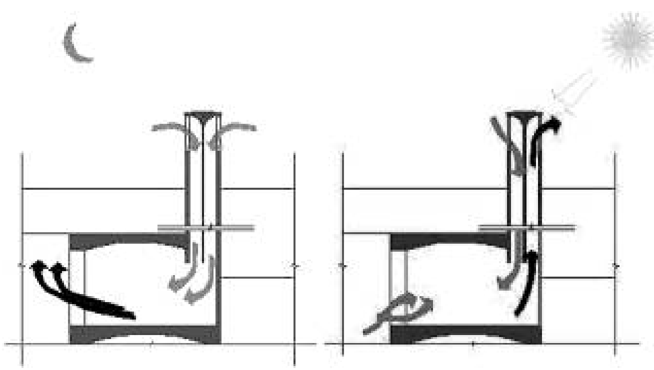

Figure 4: Wind catcher function during day and night (Azami, 2005).

When coupled with thick adobe that exhibits high heat transmission resistance qualities, the wind catcher would be able to chill lower level spaces in the middle of the day to frigid temperatures. This traditional Iranian element can help us to develop our purpose of sustainability in contemporary architecture.

The thickness of the air trap walls and the dimension of the holes inside it were designed in a manner to allow enough heat. The light warm air inside the air trap ascends and is sucked by upper elevations. As a result cool air flows from windows and doors into the house and continues all the night.

If wind blows at night, the air will circulates on the opposite direction in the air trap. In other words the cold air is sucked into the house. Of course, in such a condition the cold air flowing from the air trap duct which has been heated during the day time will warm the inlet air a little. Nevertheless air circulation again refreshes the inside temperature. During daytime the air trap acts contrary to a chimney. In other words the upper parts of the air trap has been cooled the night before and upon contacting the walls of the air trap the warm air cools down and moves towards the bottom and eventually circulates into the house and exits from doors and windows. The flow of air during daytime accelerates the ventilation process.

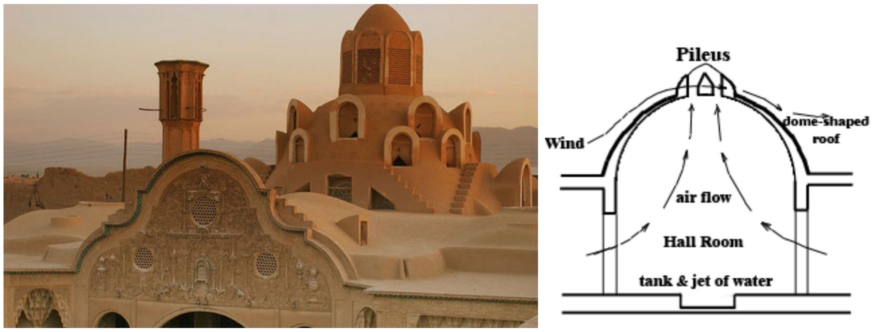

Figure 5: Schematic figure of natural ventilation in Broojerdi ha House.

4. CASE STUDY: Boroojerdi- ha house (in kashan)

The construction of this mansion, as attested by the inscription running around its reception hall, dates back to 1875 AD. According to a reliable estimate, the construction of the building was completed in 1892 AD, 18 years after it was begun, and that more than 150 masons, stucco carvers, mirror cutters and other artisans took part in its construction (Hajighasemi 1999). In this part of the paper, we will examine the mentioned design strategies to cope hot dry climate of Kashan in this traditional house.

Figure 6: Eyvan of Boroojerdi- ha House.

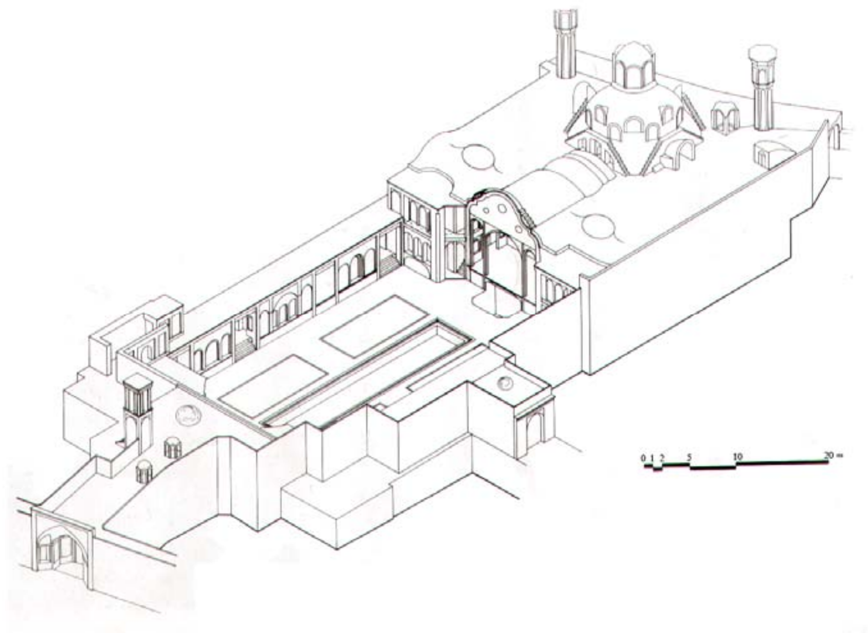

Figure 7: Isometric of Boroojerdi- ha House.

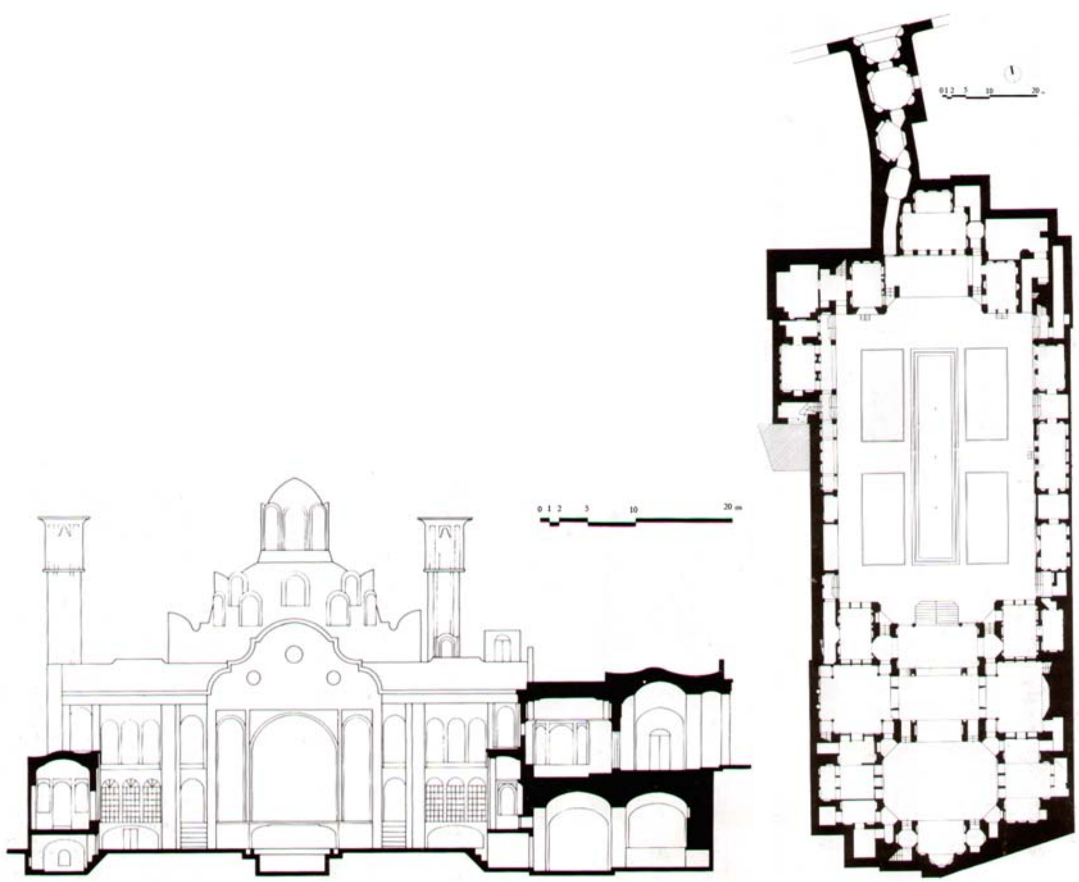

Figure 7, 8: Section and Plan of Boroojerdi- ha House

On this account, we can see macro strategies by looking at the location and orientation of the house. This building (like other buildings in desert regions) has to be surrounded by other buildings as we can see in the Figure 5 (left). This strategy allows the house to get minimum heat from its pyramid. We also can see this strategy in cold buildings that have to have minimum relationship with outdoor harsh climate.

Likewise, in the medium scale, we can see the linear form of this house that allows the building to be divided to two cubic volumes by a central courtyard. This courtyard provides deep Eyvans that create shady and cool living spaces. In addition, the building is built by earthen vernacular materials.

Last but not least, in the micro scale of consideration, we can see wind catchers and a deep Eyvan in Figure 6 that provide a cool space for users.

5. CONCLUSION

Climate responsive design strategies in hot and dry area of Kashan were discussed in this paper through three levels.

In the first level, distance between buildings, enclosed urban environment and narrow and irregular streets were considered as macro strategies. Review and development of these traditional urban patterns should be considered in hot and dry cities.

Medium scale strategies cover building form, building envelop, self-efficiency in materials and optical and thermophysical properties of building envelop in this paper. Sustainable architecture force us to re-think what we do and synchronize traditional methods of construction and the use of domestic materials.

Finally, micro scale strategies demonstrate some more relevant architectural design methods which are the same as contemporary passive systems. As an illustration, old wind-catchers have been developed into advanced passive cooling systems in recent years.

Table 2: Classification of climatic responsive design strategies of traditional architecture of Kashan.

Scales	**Climate responsive design strategies**
Macro	Distance between buildings; Enclosed urban environment; Narrow and irregular streets
Medium	Building form- Building envelope- Self-Efficiency in materials; Optical and thermophysical properties of the building envelope
Micro	Module Unite; Eyvan and Revak; Wind catcher (Air trap)

Consequently, consideration and development of the above strategies allow contemporary architects and designers to build contemporary architecture in a more sustainable, comfortable and self sufficient way.

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